HIGGS SEARCHES AT DØ

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The Higgs boson is essential to achieve electroweak symmetry breaking in the Standard Model. Results on searches for the Higgs boson in $p\overline{p}$ collisions at $\sqrt{s} = 1.96$ TeV collected with the D0 detector at the Fermilab Tevatron collider are presented. The data, corresponding to integrated luminosities between 1 fb^{-1} and 2 fb^{-1} show no excess above the expected backgrounds and as such upper limits on the production cross section of Higgs bosons are set at the 95% confidence level.

1. Introduction

The Higgs boson is predicted by the Standard Model (SM) as part of the mechanism of electroweak symmetry breaking. The mass of the Higgs boson, m_H, is not predicted by the SM, but can be constrained by fits of electroweak data to the SM. These fits favor a light Higgs boson, with the 95% confidence level upper limit at 144 GeV [1]. Searches at the LEP collider ruled out Higgs bosons with a mass below 114 GeV [2]. Including the LEP limit extends the upper limit on the Higgs mass up to 182 GeV and so puts the Higgs boson within reach of the experiments on the Tevatron collider. There are also extensions to the SM where the Higgs boson properties can be significantly different to those in the SM, for example there can be a Higgs triplet (left-right symmetric models) that gives rise to doubly charged Higgs bosons.

2. Standard Model Higgs Boson Searches

The search strategy for the SM Higgs boson is governed by the production and decay modes in the different mass ranges. The production cross section for Higgs boson production at the Tevatron is small, around $0.1 - 1$ pb for the mass range $100 < m_H < 200$ GeV. The dominant production mode is gluon fusion, followed by associated production with a vector boson that has a cross section an order of magnitude smaller than gluon fusion. The Higgs boson decays predominantly into $b\bar{b}$ pairs below a Higgs boson mass of around 135 GeV and into WW pairs above a mass of around 135 GeV. Therefore, for $m_H < 135$ GeV the analyzes make use of the associated production of the Higgs boson with a vector boson where the Higgs decays into $b\bar{b}$ pairs. In these final states, an efficient algorithm for selecting b quark jets is essential for reducing the background processes. The gluon fusion production mode is not usable because the $b\bar{b}$ final state is overwhelmed by multijet background. Above 135 GeV the analyzes use the gluon fusion production mode where the Higgs decays into WW pairs.

2.1. WH $\rightarrow l\nu b\bar{b}$, $l = e, \mu$

The WH production mode, where the W boson decays leptonically and the Higgs boson decays into a $b\bar{b}$ pair is characterized by a high transverse momentum (p_{T}) lepton, two jets and missing transverse energy ($\not\!\!E_{\mathrm{T}}$) from the neutrino. The major backgrounds to the signal are W boson production in association with heavy flavor quarks, $t\bar{t}$ and single top production. Events are required to have an electron or muon, $p_{\mathrm{T}} > 15$ GeV, two or three jets with $p_{\mathrm{T}} > 20$ GeV, where the leading jet has $p_{\mathrm{T}} > 25$ GeV and $\not\!\!E_{\mathrm{T}} > 20$ GeV. The events are then separated into two orthogonal sets, those with exactly one "tight" b-tagged jet (ST) and those with two "loose" b-tagged jets (DT). A neural network (NN) has been trained to exploit the differences in kinematics between the signal and backgrounds. Figure 1 shows the dijet invariant mass and NN output distributions in the DT sample. Cross section limits are derived from the NN output and for $m_H = 115$ GeV the observed (expected) limit is 9 (11) times the SM cross section [3].

2.2. ZH $\rightarrow \nu\nu b\bar{b}$, WH $\rightarrow \not{l}\nu b\bar{b}$

Although ZH production has a significantly lower cross section than WH production, the channel where the Z decays into a pair of neutrinos can reach competitive sensitivity due to the large branching ratio of Z $\rightarrow \nu\nu$. However, the absence of charged leptons makes this final state challenging at hadron colliders. The signal is characterized by two b jets, boosted along the direction of the Higgs momentum and large missing transverse energy from the neutrinos. The backgrounds come from two main sources, physics backgrounds where leptons were not identified (e.g. W/Z + jets, $t\bar{t}$), and the instrumental background arising from mis-measurements of multijet events

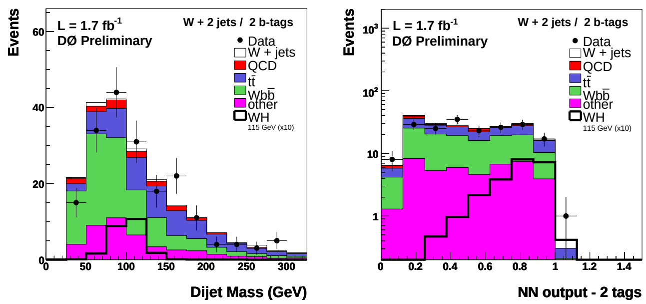

Figure 1. Distribution of the dijet invariant mass and neural network output compared to the expectation for the background processes in the DT sample in the WH analysis.

that can lead to high $\not\!\!E_T$ plus jet signals in the detector. The analysis is performed on data corresponding to a luminosity of 0.9 fb^{-1}. Events are required to have at least two jets with $p_T > 20$ GeV and $\not\!\!E_T > 50$ GeV. Both jets are required to be tagged as b quark jets and then a neural network (NN) is trained using kinematic variables to separate the signal from the remaining background. Cross section limits are derived from the NN output distribution and the contribution to the signal distribution from WH $\rightarrow l\nu b\bar{b}$ events, where the lepton was not identified is included. For $m_H = 115$ GeV the observed (expected) limit is 13 (12) times higher than the SM cross section [4].

2.3. $\mathbf{H \rightarrow WW^* \rightarrow l^+l^-\nu\nu,\ l = e, \mu}$

The WW decay mode is the dominant decay mode of the Higgs boson above around 135 GeV. The leptonic decays of the W boson provide a clean search environment for the Higgs boson, with the largest background coming from WW production. The analysis uses the three final states, e^+e^-, μ^+,μ^- and $e^\pm\mu^\mp$ and requires two high p_T oppositely charged leptons. The data sample used corresponds to an integrated luminosity of 1.7 fb^{-1}. A set of selections is used to suppress the W, Z boson and $t\bar{t}$. The Higgs mass cannot be reconstructed due to the presence of two neutrinos and a neural network is trained to discriminate between the signal and the remaining backgrounds. The neural network distribution is used to derive cross section limits and the observed (expected) cross section limit is 2.4 (2.8) times higher than the SM cross section [5].

2.4. *Combined Standard Model Higgs Limits*

The best sensitivity to the SM Higgs boson is achieved by combining all of the individual channels together in a single search. A further improvement in sensitivity is achieved by combining together the DØ and CDF searches. The combinations were updated shortly after the conference and the results for the DØ [6] and Tevatron [7] combinations are shown in Figure 2. The analyzes used in the combination use an integrated luminosity between 1 and 2.4 fb^{-1} and the observed (expected) limit is 3.7 (3.3) times the SM cross section at $m_{\mathrm{H}} = 115$ GeV and 1.1 (1.6) times the SM cross section at $m_{\mathrm{H}} = 160$ GeV. The Tevatron has already delivered more than 3 fb^{-1} of integrated luminosity to each of the two experiments and is expected to deliver a total integrated luminosity between 5 and 7 fb^{-1} before the end of the run. In additions, improvements in the sensitivity of the existing analyzes and the inclusion of extra channels (for example the tau decays of the W boson) are underway and as such the sensitivity of the SM Higgs boson searches is expected to continue to improve.

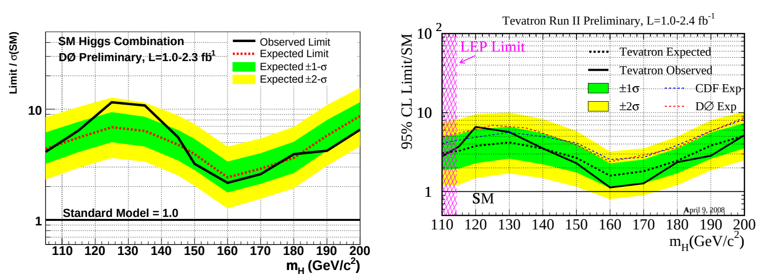

Figure 2. Combined limits on SM Higgs boson production, expressed as a ratio to the SM Higgs cross section, for the DØ combination (left) and the combination of the DØ and CDF analyzes (right).

3. Search for Doubly Charged Higgs Boson

Models such as left-right symmetric models, Higgs triplet models and little Higgs models all predict doubly charged Higgs bosons. In order for such models to match the experimental value for the parameter $\rho = m_{\mathrm{W}}^2/(\cos\theta_{\mathrm{W}} m_{\mathrm{Z}})$ the coupling to W boson pairs is typically required to vanish, with the result that the dominant decay mode is to like-sign leptons. The discovery of a doubly charged Higgs boson would be a clear observation of physics beyond the SM.

A data sample corresponding to an integrated luminosity of 1.1 fb^{-1} is used to search for $p\overline{p} \rightarrow \text{H}^{++}\text{H}^{--} \rightarrow \mu^+\mu^+\mu^-\mu^-$, resulting in a final state containing four muons. In order to keep the efficiency for the signal high, three high p_{T} muons are selected, of which two must have the same charge. After the selections, the dominant background contribution is from ZZ events. Three events in the data pass all the selections, in good agreement with the background expectation of 2.3. Cross section limits are derived from the invariant mass distribution of the two muons with the same sign charge. These limits can be compared to the theoretical cross sections for left and right handed doubly charged Higgs bosons (assuming 100% branching ratio to muons), leading to mass limits of 150 GeV for left handed and 127 GeV for right handed doubly charged Higgs bosons, which represent the most stringent limits to date [8].

4. Conclusions

The Higgs boson still remains the one missing piece of the SM. The searches for the SM Higgs boson at DØ continue to improve in sensitivity, and when combined with the CDF results the observed limit at $m_H = 160$ GeV is now only a factor of 1.1 above the expectation from the SM. The Tevatron is expected to deliver around $6-8$ fb^{-1} by the end of the run and as such the next couple of years promise to be exciting times at DØ and the Tevatron.

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